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USDA Forest Service

Rocky Mountain Forest and
Range Experiment Station

Effects of Mountain Home Developments on Surface Water Quality: A Case Study

by

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Four mountain home developments, located adjacent to perennial streams, did not consistently increase orthophosphate, chloride, indicator bacteria, or suspended solids above existing levels of upstream contamination.

Keywords: water quality, mountain homes, Colorado Front Range, septic systems, streamflow

RM-396 FOREST AND RANGE
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JUL 2 1981

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Management Implications

During a 2-year period, there was little statistical evidence that four specific mountain home developments in the northern Colorado Front Range increased fecal contamination, organic, or inorganic pollution of streams. High background levels of contaminants upstream apparently prevented detection of additional amounts of these pollutants. High background levels of upstream contamination are associated with potential and subtle bacterial and probable nitrate pollution of groundwater, the major source of domestic water. The relatively high levels of upstream pollution point to a great need for small community wastewater treatment plants and better home sewage treatment systems. Septic systems near live stream channels should be phased out, because they provide minimal biological treatment. Aerobic systems with disinfection, along with chemical toilets and sealed storage vaults, should be considered as substitutes.

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Introduction

The east slope of the Colorado Rockies has become increasingly popular for residential and second-home developments. The mountain home developments vary considerably in design, and many are near streams and lakes.

Past work suggests light residential and second-home developments can degrade water quality in mountainous areas. Water quality problems stem mainly from homesite development (cutting, filling, leveling, etc.), road systems, and sewage disposal (Worms and Brickler 1967, Vice et al. 1968, Millon 1970; Howe 1972; U.S. Environmental Protection Agency 1973, Brickler and Utter 1975, Johnson and Middlebrooks 1975, Aukerman and Springer 1976, Segal 1976, Zimmerman 1979, and Ponce and Gary 1979), not from recreational uses.

Although considerable information exists on the effect of forestry and livestock practices on water quality and the environment (Montgomery 1976, Rowe and Merryman 1977), the impact of mountain home development on the quality of surface water draining the Front Range has not been fully explored.

Study Area and Home Developments

The study area is near Estes Park, Colo. (fig. 1). Average annual precipitation ranges from 40 to 65 cm. Summer thunderstorms account for more than half of the

annual precipitation. Winter precipitation is mostly snow, and normally persists until May at the higher elevations.

The area is underlain by a variety of metamorphic and granitic rocks which have weathered to weakly developed, coarse textured, and highly permeable soils. Valley bottoms contain finer textured and less permeable alluvial soils. Overstory vegetation is comprised primarily of ponderosa pine (*Pinus ponderosa* Laws), intermingled with quaking aspen (*Populus tremuloides* Michx.), Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), blue spruce (*Picea pungens* Engelm.), and Engelmann spruce (*Picea engelmannii* Parry). Willow (*Salix* spp.), alder (*Alnus* spp.), birch (*Betula* spp.), and chokeberry (*Prunus* spp.) are the dominant woody understory plants along stream channels.

Four home developments were selected for study based on volume of streamflow, number of homes per kilometer of stream distance, and method of sewage treatment. Sampling sites were located above and below housing areas in each development.

Home developments designated areas 1 and 2 are in the community of Raymond, Colo., on the middle fork of the St. Vrain Creek, at elevations of about 2,380 m. Area 1 is between sites 1 and 2 (fig. 1), and contains about 1.3 km of stream reach. This development has high streamflow (mean discharge 2.27 m³ per second) and high housing density—67 houses on both sides of the stream (52 homes per km of stream)—and conventional septic systems (fig. 2).

Area 2 is adjacent to and downstream from area 1, and is bounded by sampling sites 2 and 3 (fig. 1). Stream reach is 3.6 km, and stream discharge was the same as area 1. This area has moderate density housing—about 122 homes on both sides of the stream (34 homes per km of stream)—and mainly septic systems (fig. 2).

Most homes in areas 1 and 2 are more than 30 years old, about 35% are occupied all year, and most are within 50 m of the stream. Access to the areas is by paved highway located within 2 to 4 m of the stream. Streambanks in both areas are tree-lined, lined with large rocks, and generally stable. The water supply for most homes comes from either drilled or hand-dug wells, but most residents haul drinking water because of concern about water quality.

Area 3 is in the community of Allenspark, at about 2,600 m elevation, along a 1.4-km stretch of Willow Creek, and bounded by sample sites 4 and 5 (fig. 1). This area has low streamflow (mean discharge 0.06 m³ per second), high density housing—77 homes on either side of the stream (55 homes per km of stream)—, and mostly septic systems (fig. 2). Most houses are within 50 m of the stream channel, more than 30 years old, and have mainly gravel access roads and driveways. Streambanks are tree-lined and stable. Water supply comes mainly from wells.

Area 4 is on a 1-km section of Fish Creek, near Estes Park, at about 2,285 m elevation, and bounded by sites 6 and 7 (fig. 1). Streamflow is low (mean discharge 0.06 m³ per second), housing density moderate on either side of the stream (32 homes per km of stream), and is served by a gravity flow sewage collection system leading to a secondary municipal treatment plant (fig. 2). Most homes are less than 10 years old, within 100 m of the stream, and have access by paved road. Domestic water is mainly provided by a water district. Streambanks are mainly vegetated by shrubs and grass, and are relatively stable. Surface runoff from summer rains occurred occasionally from several lots.

Methods and Materials

Physical, Chemical and Biological Analysis

Stream discharge (Q) was determined by a velocity-area method using a direct reading current velocity meter. From these data, a discharge-height rating curve was developed for each site and used to estimate stream discharge during summer storms.

Suspended solids (SS) were determined by filtering and gravimetric procedures outlined in Standard Methods (American Public Health Association 1971).

Chloride (Cl) was determined using the Argentometric Method (American Public Health Association 1971).

Orthophosphate (PO₄) concentrations were determined by the ascorbic acid method (American Public Health Association 1971), and as modified by Hach (Hach Chemical Co. 1975).

Nitrate-nitrogen (NO₃-N) determinations were suspect and subsequently were discarded, because most test

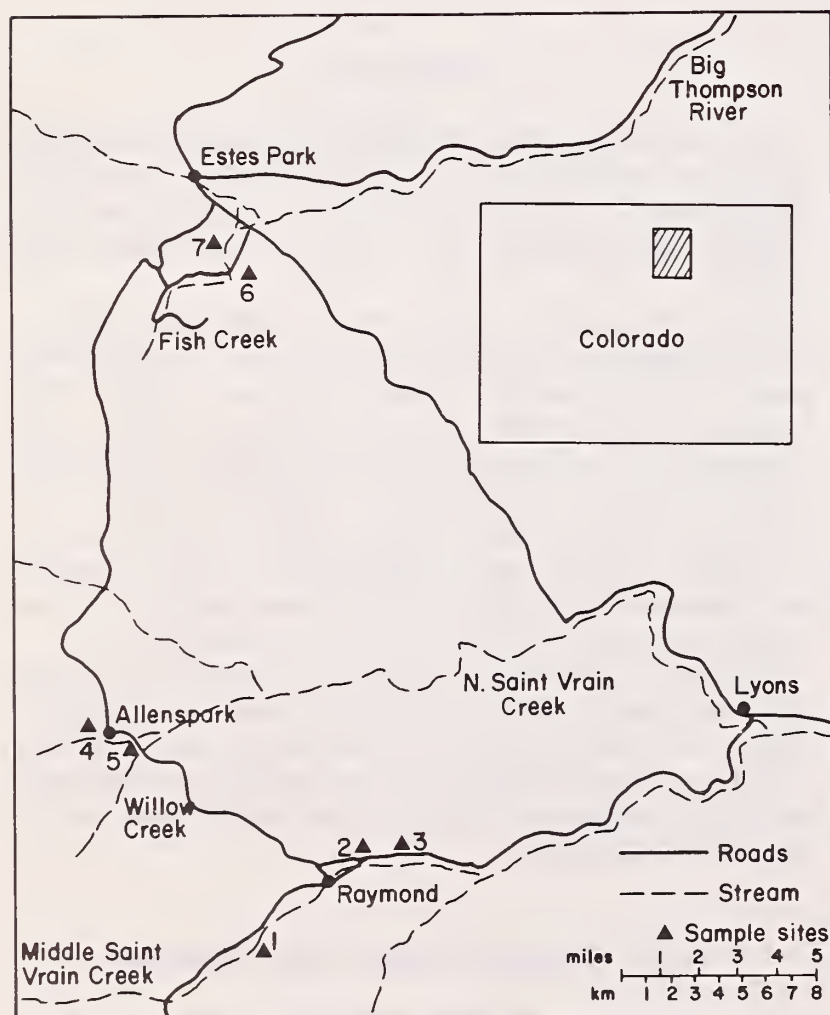


Figure 1.—Location of home areas. Numbers show sampling sites.



Figure 2.—Home settings in Raymond (areas 1 and 2), near Allenspark (area 3), and near Estes Park, Colorado (area 4).

results were at or below the accuracy limits of the test procedure. However, $\text{NO}_3\text{-N}$ concentrations of shallow groundwater in areas 1 and 2 were reported to range below 1.5 mg/l (Zimmerman 1979).

Fecal coliform (FC) and fecal streptococci (FS) were determined by the membrane filter technique (American Public Health Association 1971). Serial dilutions were utilized in all bacteriological analyses. FC were incubated in a water bath at $44 \pm 0.2^\circ \text{C}$ for 24 hours and FS in an air incubator at $35 \pm 0.5^\circ \text{C}$ for 48 hours.

Sample Collection and Frequency

Water samples for chemical and physical analyses were taken in 1-liter Nalgene bottles. Water for bacteriological analysis was obtained in sterilized 250-ml glass bottles. Grab samples, usually one per site, were collected in midstream and depth integrated. Bacteriological analyses were performed upon returning to the laboratory (within 6 hours), and physical and chemical analyses were completed within 24 hours of collection.

Samples were collected about mid-morning each Sunday, beginning in late May and continuing through August, during 1977 and 1978. Thereafter, samples were collected every 2 weeks, on Sundays, through September of each year. The samples were analyzed for SS, PO_4 , Cl, FC, and FS. Diurnal sampling performed at each area early in the study indicated composite sampling was not necessary.

Two types of rainstorms, frontal and convective, also were monitored. Data collection was sporadic because of the random frequency and location of storms over the specific study sites. Rainfall quantities of monitored storms did not exceed 10 mm, typical for July and August. Samples were collected once each hour at areas 1 and 2 during one frontal rain event lasting 6 hours, on August 3, 1978. Two typical convective storms or summer showers, of variable intensity, and lasting from 20 to 30 minutes, also were sampled at area 3 on July 17, 1978 and August 25, 1978. Water samples also were taken at area 4 during two convective storms (similar to above) on July 29, 1978 and August 26, 1978. Water samples for the convective storm events were taken simultaneously at each site, at roughly 10-minute intervals, and were analyzed for SS, FC, and FS.

Data collected routinely and during storms within each development (upstream and downstream sites) were analyzed statistically using analysis of variance. The minimum significance for acceptance of hypothesis of no difference was the 0.10 level, unless otherwise noted.

Results and Discussion

Water Quality Parameters

Various pollution standards are in use by federal, state, and local agencies as indicators of water quality. A brief discussion of the parameters determined for this study is as follows:

Suspended solids.—Result mainly from erosion and consist generally of sand, silt, colloids, organic detritus, and plankton. SS concentrations consistently above 80 mg/l usually harm fish and other aquatic life (McKee and Wolf 1963).

Chloride.—Ions are found in most natural waters and are seldom a health problem if concentrations remain less than 125 mg/l (McKee and Wolf 1963). Cl also may be derived from human and animal sewage. Any point increase in Cl probably indicates a nearby pollution source.

Orthophosphate.—The main source of phosphates, other than geologic weathering of rocks, is feedlots, fertilizers, insecticides, detergents, and sewage effluents (U.S. Environmental Protection Agency 1976). PO₄ concentrations below 0.2 mg/l generally do not cause undesirable enrichment and aquatic plant growth in streams (McKee and Wolf 1963).

Nitrate-nitrogen.—The most completely oxidized and most stable form of nitrogen in surface water, NO₃-N is a natural fertilizer and generally stimulates unwanted aquatic plant growth when concentrations are above 0.3 mg per liter. Detectable NO₃-N in streams usually indicates excessive applications of fertilizer or leachings from septic tanks. The maximum safe limit of NO₃-N concentration set for domestic water supplies is 45 mg/l (McKee and Wolf 1963).

Fecal coliform and fecal streptococci.—These indicator bacteria are always present in intestinal tracts of warm blooded animals and are eliminated in large numbers in fecal waste. While not pathogenic themselves, their presence usually indicates that intestinal waste products have reached stream water. Water supplies consistently containing fecal coliform densities greater than one colony per 100 ml are general unacceptable for drinking (U.S. Environmental Protection Agency 1975).

Routine Sampling

Data collected routinely are summarized in table 1. The first study year, 1977, had a drier than usual winter, with only 10 cm of precipitation recorded at Allenspark. Precipitation the following winter was 25 cm, near the long-term seasonal average. As a result of high winter precipitation, spring snowmelt runoff and baseflow was three to four times greater at all areas in 1978 (fig. 3).

In area 1, with high streamflow, high housing density, and septic systems, SS were significantly different ($P = 0.05$) in 1977 and PO₄ ($P = 0.01$), and FS ($P = 0.10$) in 1978. Cl and FC concentrations remained virtually unchanged between years and throughout the stream reach.

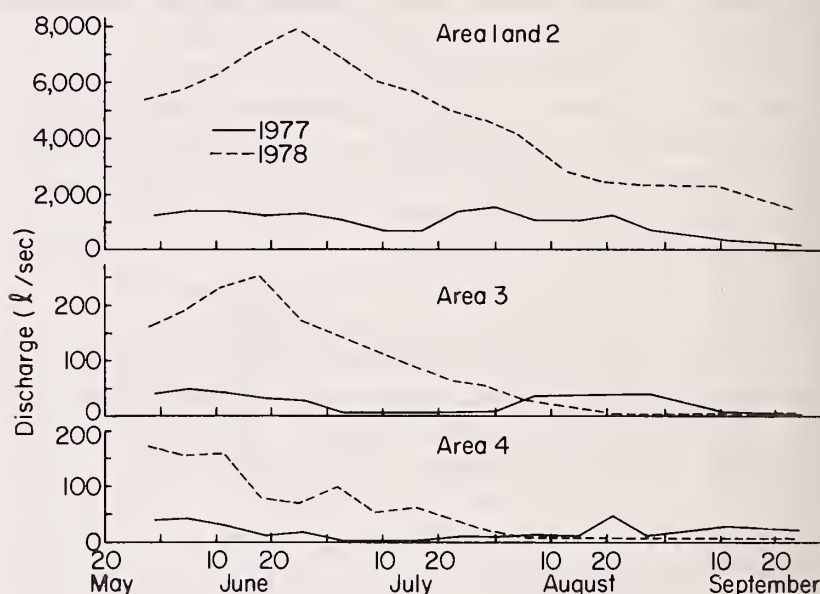


Figure 3.—Discharge for streams in the home areas.

Table 1.—Mean and standard deviation of data collected routinely during 1977 and 1978.

Parameter	Area 1		Area 2		Area 3		Area 4	
	U ¹	D ²	U	D	U	D	U	D
1977								
Q(m/sec)	0.84(0.30) ³	0.88(0.32)	0.88(0.32)	0.91(0.35)	0.02(0.01)	0.03(0.02)	0.01(0.01)	0.01(0.01)
SS(mg/l)	3.7(2.6)	4.3(2.3)	4.3(2.3)	4.1(2.5)	4.8(4.9)	4.2(3.2)	10.0(3.4)	12.2(5.4)
PO ₄ (mg/l)	0.12(0.07)	0.15(0.20)	0.15(0.20)	0.20(0.26)	0.13(0.07)	0.18(0.20)	0.18(0.10)	0.18(0.11)
Cl(mg/l)	5.0(0.7)	4.9(0.8)	4.9(0.8)	5.4(1.6)	4.0(0.7)	4.3(0.9)	4.2(0.6)	4.7(0.4)
FC(col/100 ml)	26(28)	27(29)	27(29)	26(26)	8(15)	14(14)	125(125)	188(233)
FS(col/100 ml)	170(369)	139(252)	139(252)	122(191)	21(31)	29(24)	129(173)	185(214)
1978								
Q(m/sec)	3.51(1.38)	3.62(1.41)	3.62(1.41)	3.72(1.44)	0.08(0.07)	0.08(0.07)	0.04(0.04)	0.05(0.06)
SS(mg/l)	5.3(0.6)	5.4(0.9)	5.4(0.9)	5.8(0.8)	6.9(1.0)	7.2(1.1)	15.2(2.7)	16.4(3.0)
PO ₄ (mg/l)	0.05(0.02)	0.07(0.03)	0.07(0.03)	0.06(0.02)	0.07(0.04)	0.09(0.04)	0.18(0.12)	0.18(0.11)
Cl(mg/l)	4.5(0.03)	4.5(0.2)	4.5(0.2)	4.6(0.3)	4.2(0.4)	4.1(0.5)	4.9(0.5)	4.9(0.5)
FC(col/100 ml)	36(57)	26(40)	26(40)	35(93)	4(8)	13(15)	102(135)	130(138)
FS(col/100 ml)	472(590)	632(821)	632(821)	531(580)	107(99)	182(196)	826(1494)	733(1167)

¹Upstream sampling site

²Downstream sampling site

³Numbers in parenthesis are standard deviations

SS concentrations, although statistically different in 1977, were so low that any impact on the aquatic ecosystem was discounted. Significantly higher PO₄ concentrations suggested possible nutrient loading from septic systems through the study reach. In addition, FS indicator bacteria counts also suggested increased contamination, probably caused by sewage effluent in area 1.

In area 2, with high streamflow, moderate housing density and septic systems, no significant increases in any of the water quality parameters monitored during either year were indicated. In general, concentrations were about the same during both years, with exception of FS counts which tripled at both upstream and downstream sampling sites during 1978. The same increases also occurred upstream in area 1 and appeared to indicate that bacterial contributions were mainly from upstream sources.

In area 3, with low streamflow, high housing density, and septic systems, CI was significantly different ($P = 0.06$) during 1977 and PO₄ ($P = 0.01$) during 1978. The mean differences, while small, may indicate subtle pollution from home developments. The concentrations of both constituents were similar to those of areas 1 and 2, while the associated concentrations of FS and FC did not suggest a direct impact by home development.

In area 4, with low flow, moderate housing density, and sewage piped off-site to a wastewater treatment plant, SS ($P = 0.07$), CI ($P = 0.01$) and FS ($P = 0.06$) were significantly different during 1977, and SS ($P = 0.01$) again during 1978. Significant differences in SS values, while relatively low, probably were related to soil disturbance associated with the more recent home development. Soil disturbed by site development was readily available for transport to the stream. Significant in-

creases in FS apparently were influenced by home pets and local livestock, because the development did not use septic systems.

Storm Sampling

The low rainfall amounts during the five observed storms did not result in noticeable surface runoff. A comparison of mean values for routine sampling and storm sampling is summarized in table 2. A 6-hour frontal storm on August 3, 1978 was monitored at areas 1 and 2. Stream discharge before and during the storm was as follows:

	Discharge (m ³ /sec)	
	Before storm	Maximum during storm
area 1	3.115	3.285
area 2	3.200	3.370

Stream discharge increased only slightly during the storm and change in SS was minor. The high background concentrations of bacteria did not further increase in home areas 1 and 2.

Two convective storms were sampled at area 3 — a 30-minute storm on July 17, and a 20-minute storm on August 25, 1978. Stream discharge during the storms was as follows:

	Discharge (m ³ /sec)	
	Before storm	Maximum during storm
July 17, 1978	0.034	0.057
August 25, 1978	0.023	0.037

Streamflow increased about 66% (0.023 m³ per second) during the first storm and 63% (0.014 m³ per second)

Table 2.—Mean comparison of suspended solids (milligrams per liter), and fecal coliform and fecal streptococci (colonies per 100 milliliters), for routine versus storm sampling during five storms.

Area		Routine Sampling						Storm Sampling					
		1977			1978								
		SS	FC	FS	SS	FC	FS	SS	FC	FS	SS	FC	FS
1	U ¹	3.7	26	170	5.3	36	472	August 3, 1978					
								6.8	126	873	—	—	—
	D ²	4.3	27	139	5.4	26	632	6.9	103	902	—	—	—
2	U	4.3	27	139	5.4	26	632	6.9	103	902	—	—	—
	D	4.1	26	122	5.8	35	531	7.3	77	863	—	—	—
3	U	4.8	8	21	6.9	4	107	July 17, 1978			August 25, 1978		
								8.1	79	2,433	7.1	28	910
	D	4.2	14	29	7.2	13	182	8.3	132	2,500	7.4	32	1,193
4	U	10.0	125	129	15.2	102	826	July 29, 1978			August 26, 1978		
								18.3	346	5,720	16.7	178	7,160
	D	12.2	188	185	16.4	120	733	19.6	240	5,980	18.1	252	7,240

¹Upstream sampling site.

²Downstream sampling site.

during the second storm. However, analysis of water quality data collected six and four times during the first and second storms, respectively, did not indicate significant changes in SS, FC, and FS (table 2).

Two convective storms also were sampled at area 4 in 1978 (table 2). Discharge increased from about 0.007 to 0.21 m³ per second during one storm in July and from 0.004 to 0.008 m³ per second for a storm in August. Each storm was sampled five times. SS concentrations were relatively low, but were significantly higher downstream during both storms. FC and FS densities were greatly elevated, apparently in response to the bank wetting (Ponce and Gary 1979), but bacteria counts between upstream and downstream sites were not significantly different.

Conclusions

Measurements taken during a 2-year period and during selected summer storms indicated that paired relationships between upstream and downstream sites, in housing areas at Raymond, Allenspark, and near Estes Park, Colo. generally were not sensitive to specific impacts on stream water quality. Events of major summer storms and periodic flooding were not observed, and it is not known if such storms would indicate similar results. High background levels of upstream water contaminants known to exist (Zimmerman 1979) probably masked any subtle impacts of sewage effluents at Raymond and Allenspark. The high background levels of upstream bacterial pollution under present development and use pose minor human health hazards, as long as raw stream water is not used as potable water within any of the home developments. Under present development and use, there is little evidence of upstream organic loading within the four study areas that will significantly affect downstream use of water.

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